International Space Station Lithium-Ion Battery Start-Up

Space Power Workshop
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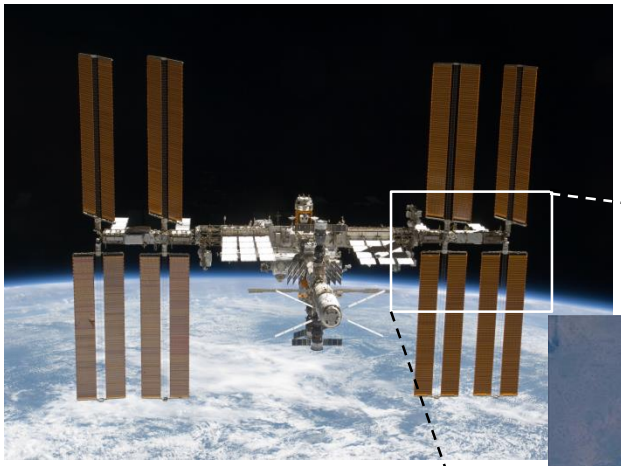
ISS Li-Ion Battery - Outline

- Configuration of Existing ISS Electric Power System
- Final Flight Adapter Plate and Battery Design
- Launch and Installation
- Battery Charge Control and LEO Cycle Test Data
- On-Orbit cycling data
- Cell and ORU Life Test

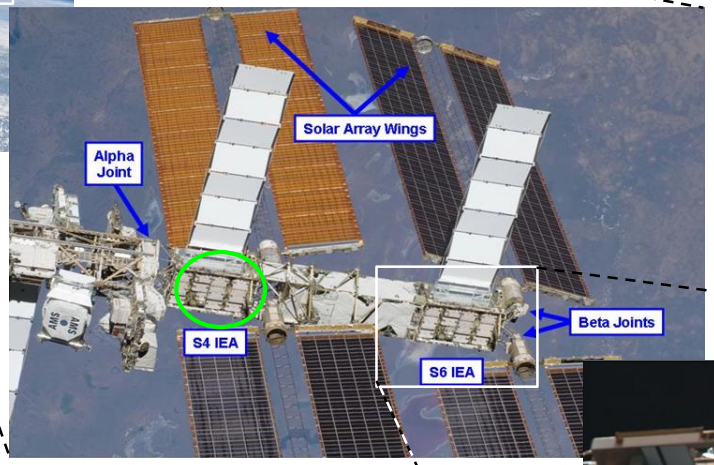
ISS Configuration - Battery Locations

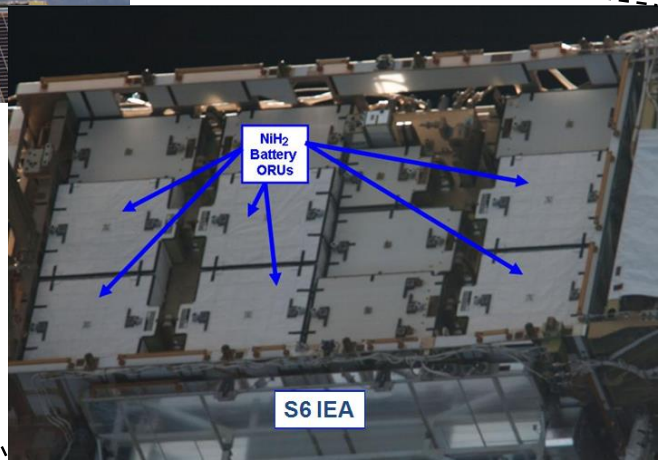


Batteries are located in the 4 Integrated Equipment Assemblies (IEAs)

2 Power Channels per IEA

8 Power Channels total



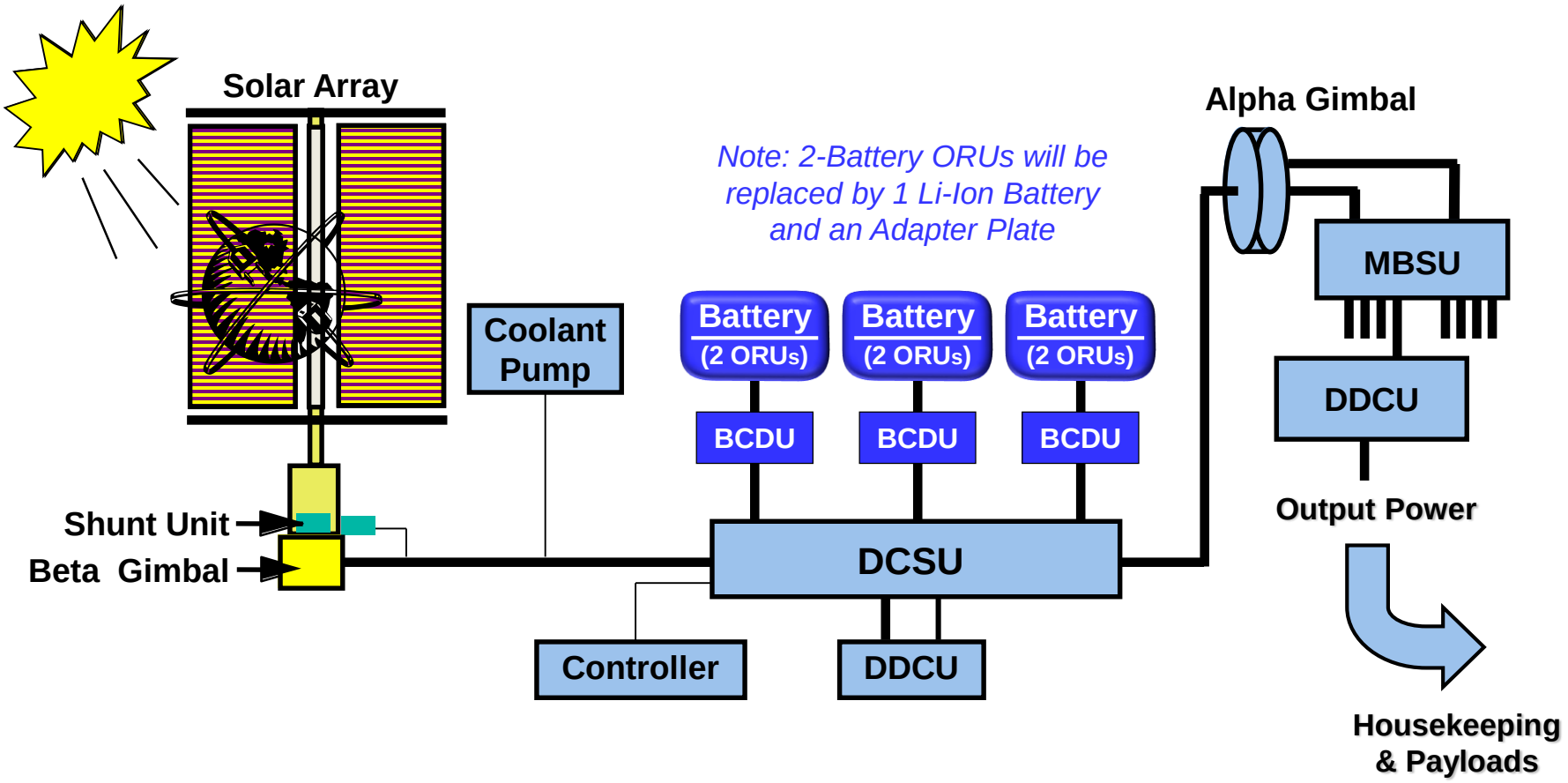


6 Ni-H_2 ORUs per channel – 48 total

1 Li-Ion and 1 Adapter Plate to replace
2 Ni-H_2 – 24 total Li-Ion batteries

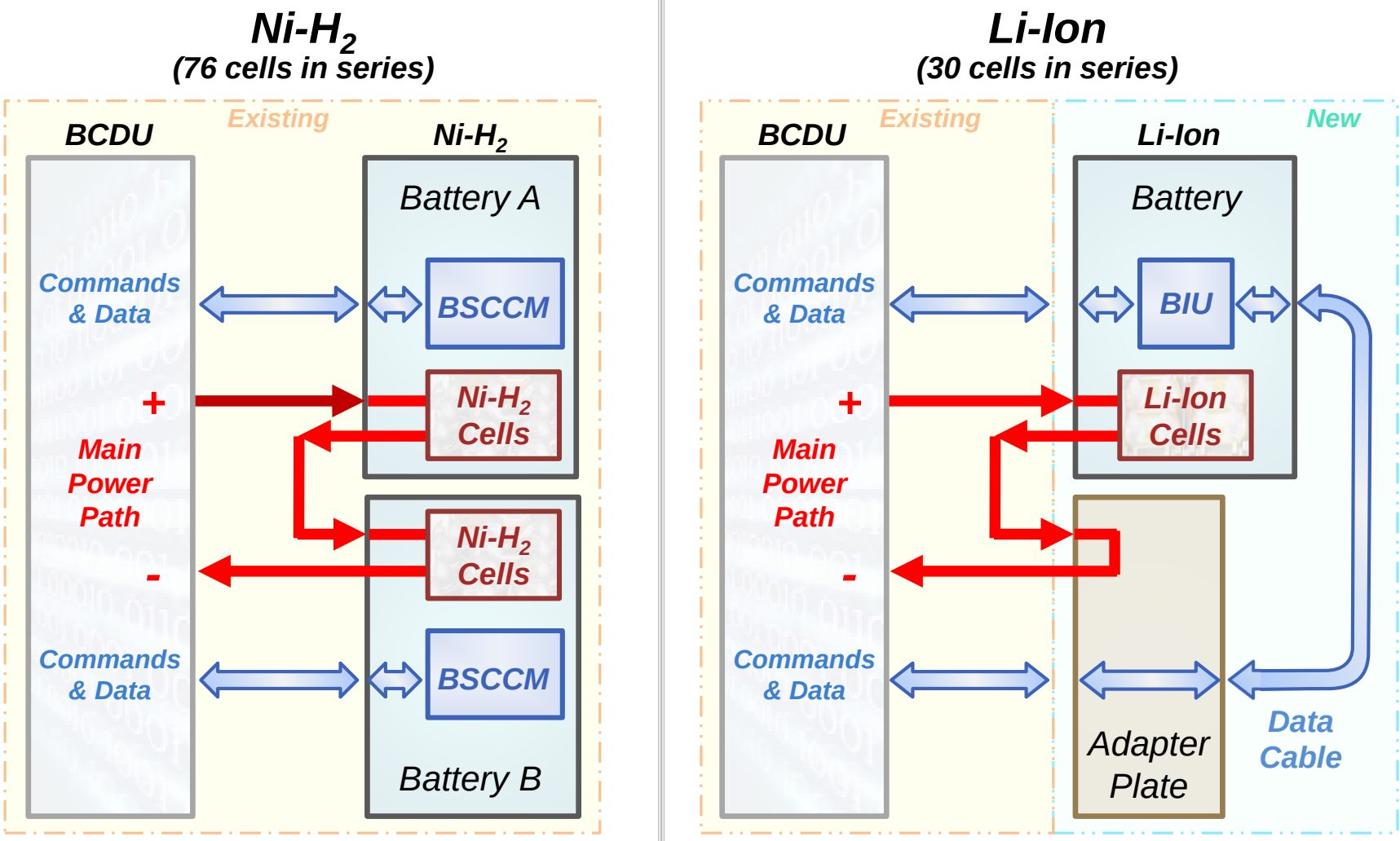
ISS Configuration - EPS Schematic

Electrical Power Channel – 1 of 8



EPS:: Electric Power System
BCDU: Battery Charge / Discharge Unit
DCSU: DC Switching Unit
DDCU: DC-to-DC Converter Unit
MBSU: Main Bus Switching Units

ISS Upgrade to Li-Ion



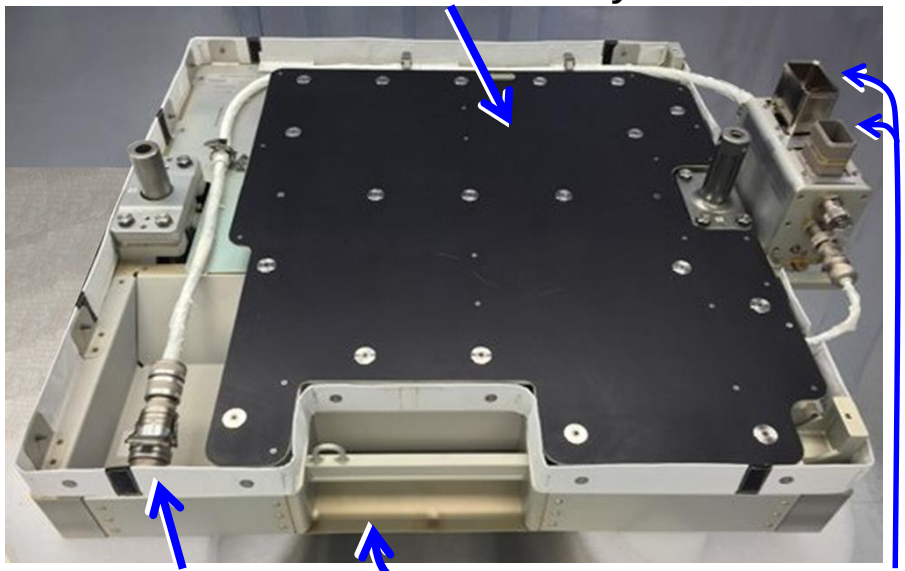
BCDU: Battery Charge / Discharge Unit
BIU: Battery Interface Unit
BSCCM: Battery Signal Conditioning and Control Module

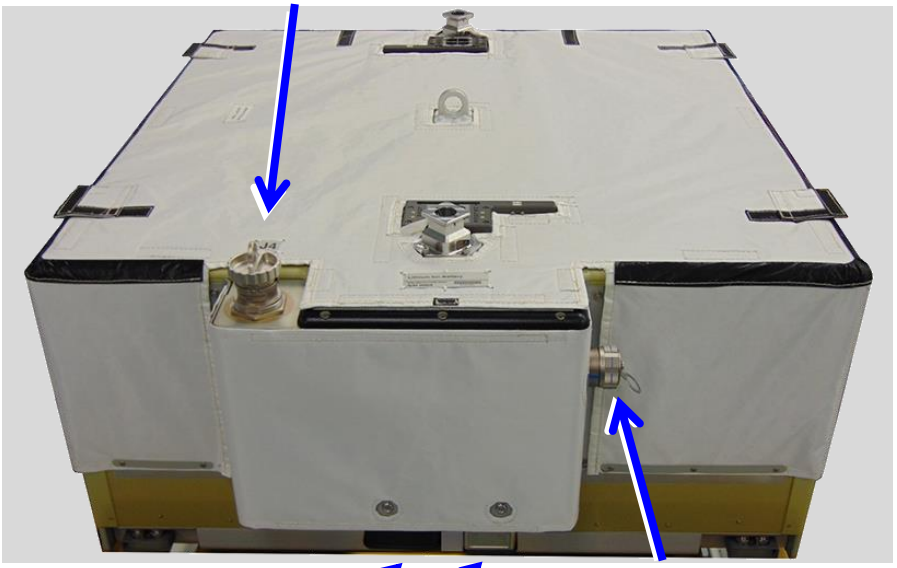
ISS Li-Ion Orbital Replacement Units

(Direct drop in replacement for Ni-H_2)

Heater Matt
Heater Plate Assembly

J4
Connector





P4 Connector
(stowed for launch)

EVA
Hand Hold

P1 & P2
Connectors

J3 Test
Connector

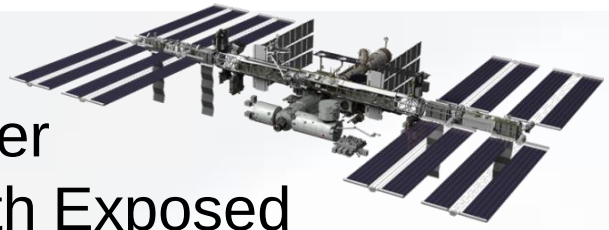
Adapter Plate ORU

Dimensions (LxWxH): ~ 41” x 36” x 15”
Spec Weight: 85 Lbs

Li-Ion Battery ORU

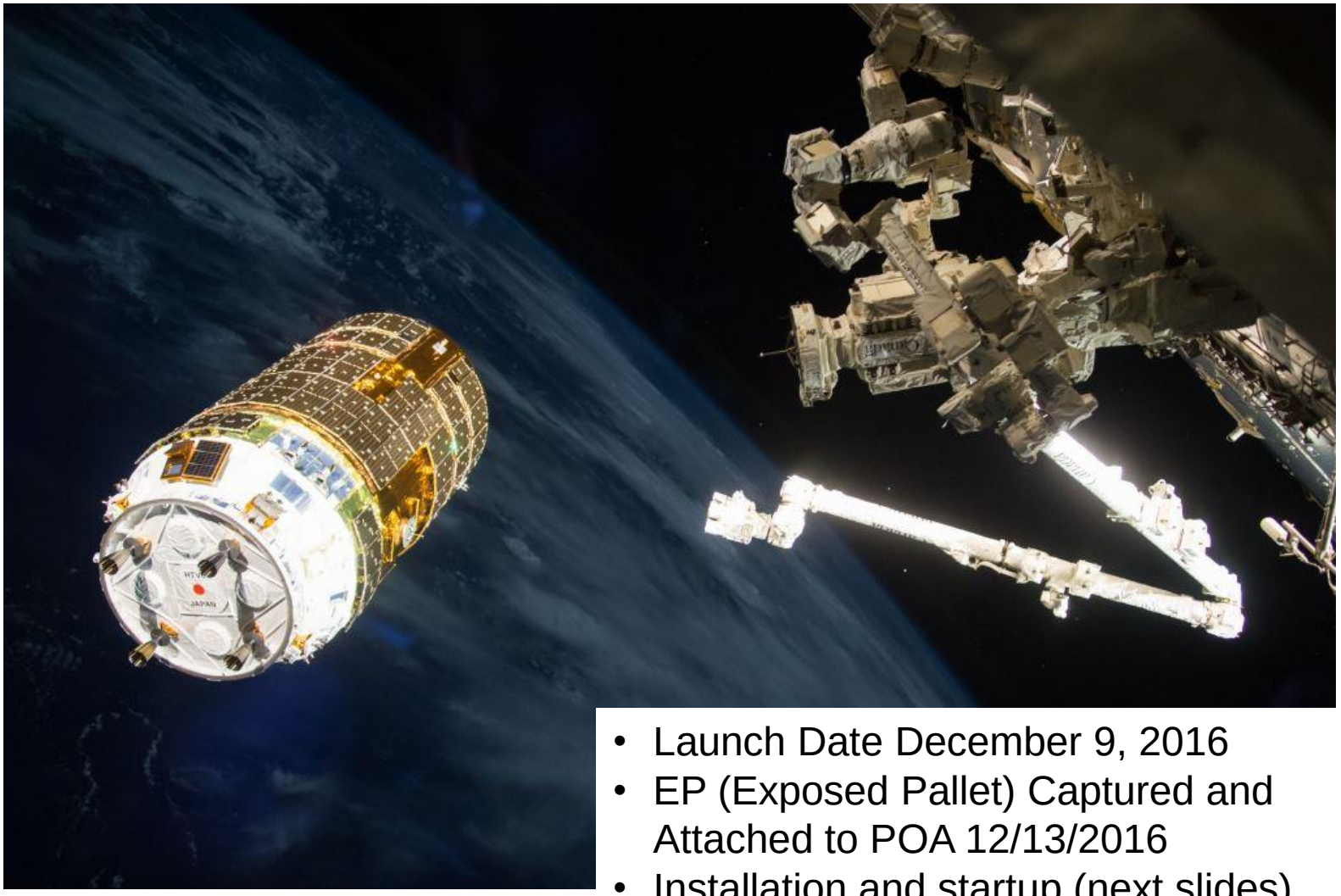
Dimensions (LxWxH): ~ 41” x 37” x 21”
Spec Weight: 435 Lbs

ISS Li-Ion Flight Battery Status



- 6 Flight Li-Ion Adapter Plates integrated with Exposed Pallet in Japan, Tomioka: April 2016
- 6 Flight Li-Ion Batteries integrated with Exposed Pallet in Japan, Tanegashima: May 2016
- Final charge to 4.1V: May-June 2016
- Launch on HTV6: December 9, 2016
  - Each IEA will have 3 Li-Ion ORUs and 3 Adapter Plate ORUs
- Installation and start-up on ISS:
  S4 3A channel – Jan. 6, 2017
  S4 1A channel, Jan. 13, 2017

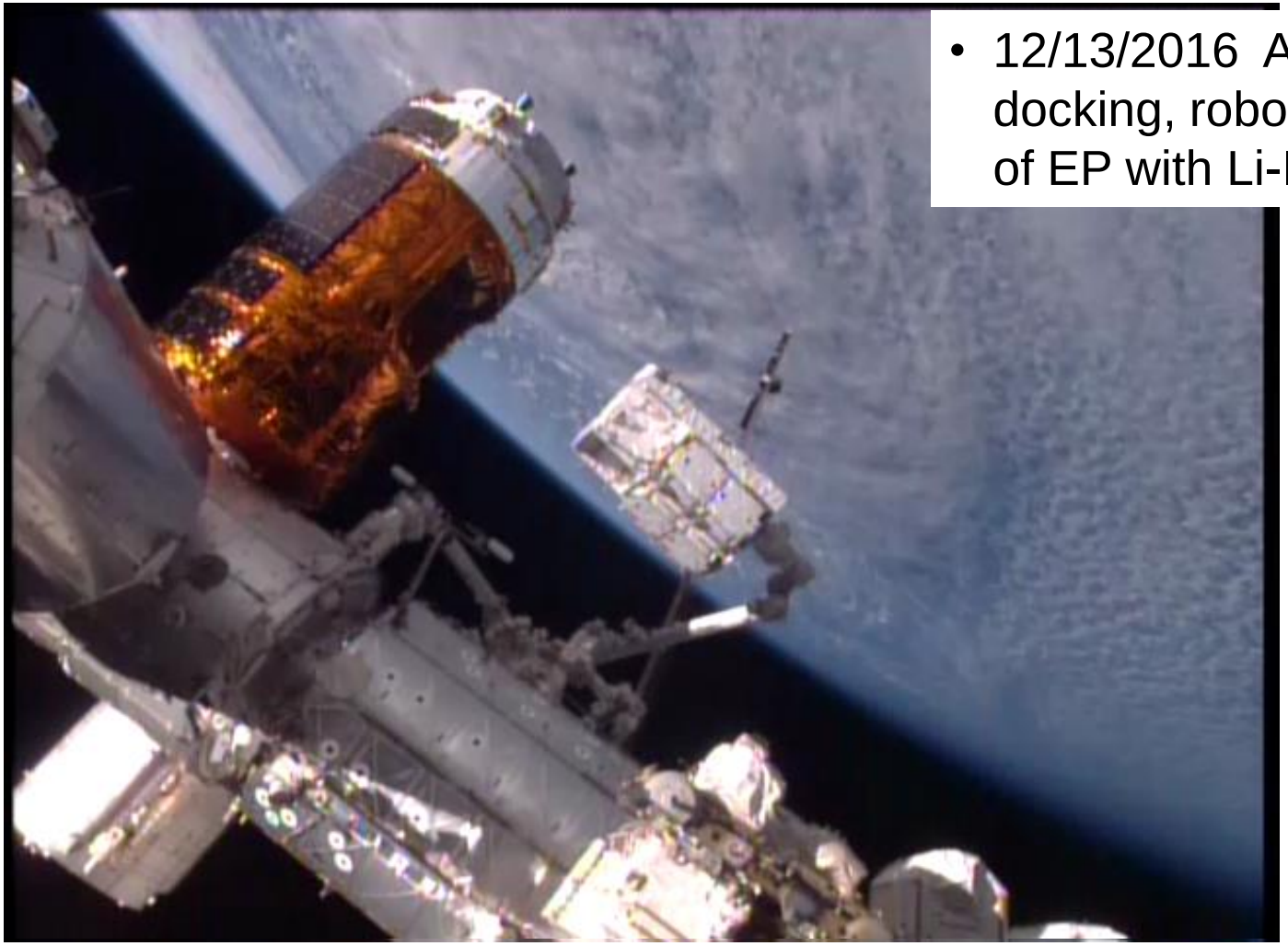
Docking of HTV6 to ISS



HTV Approach to ISS

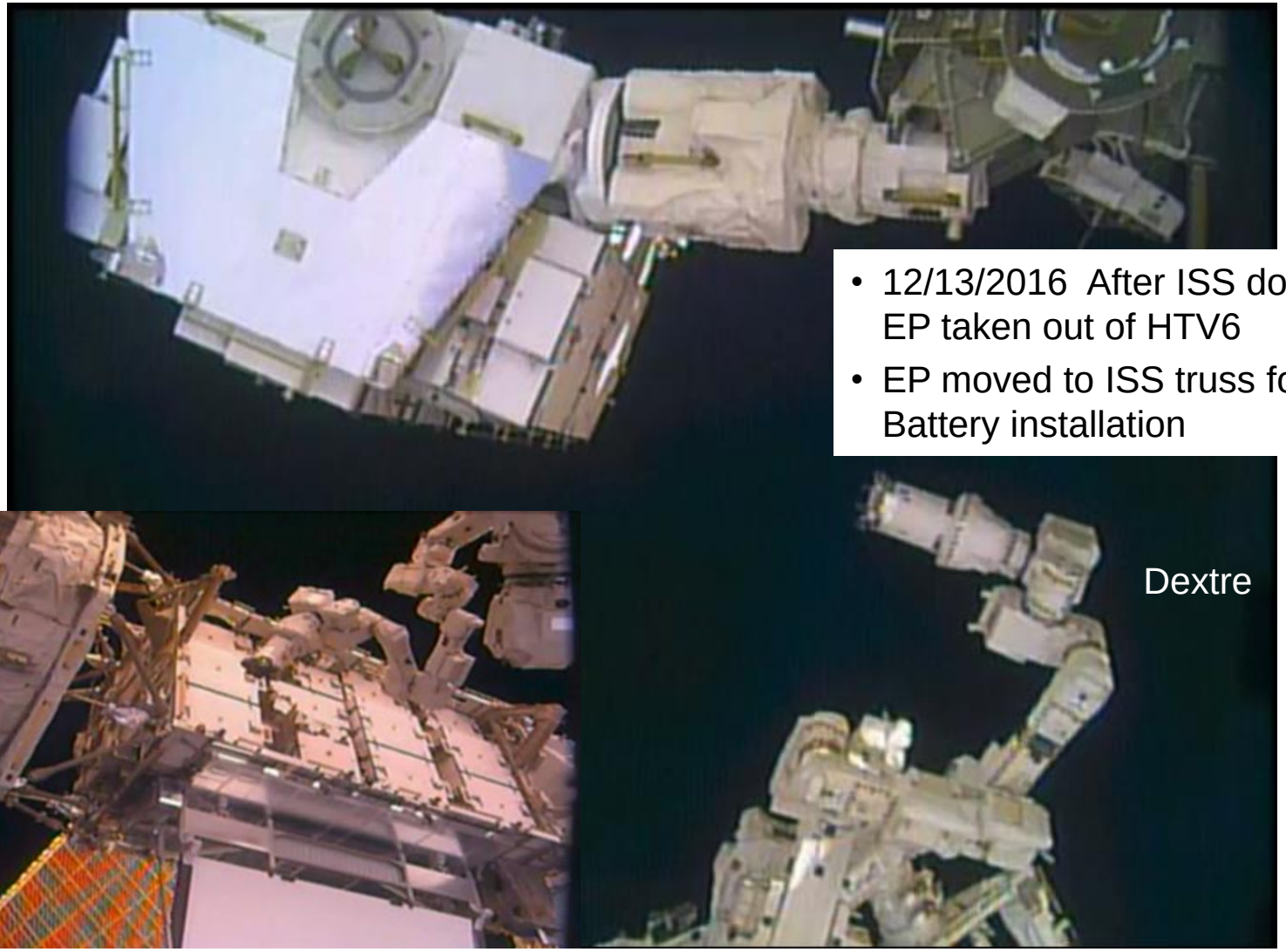
- Launch Date December 9, 2016
- EP (Exposed Pallet) Captured and Attached to POA 12/13/2016
- Installation and startup (next slides)

Removal of Exposed Pallet with Li-Ion ORUs



- 12/13/2016 After docking, robotic removal of EP with Li-Ion ORUs

Moving the Li-Ion ORUs



- 12/13/2016 After ISS docking, EP taken out of HTV6
- EP moved to ISS truss for Battery installation

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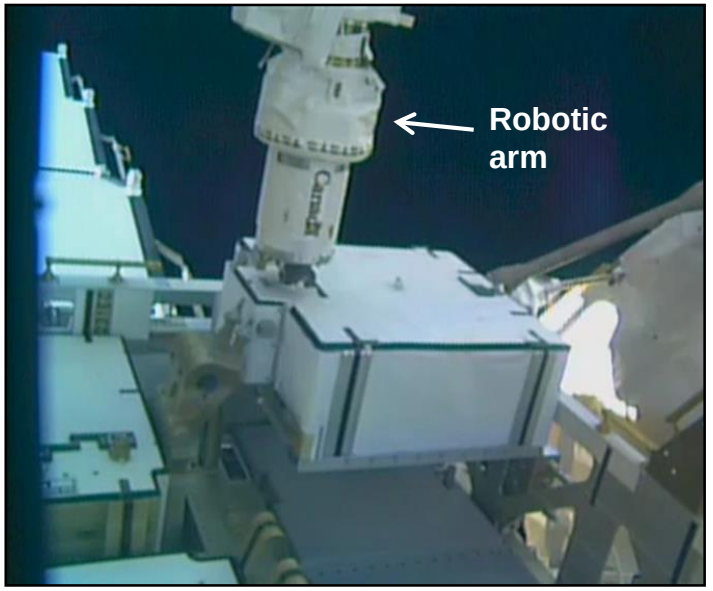
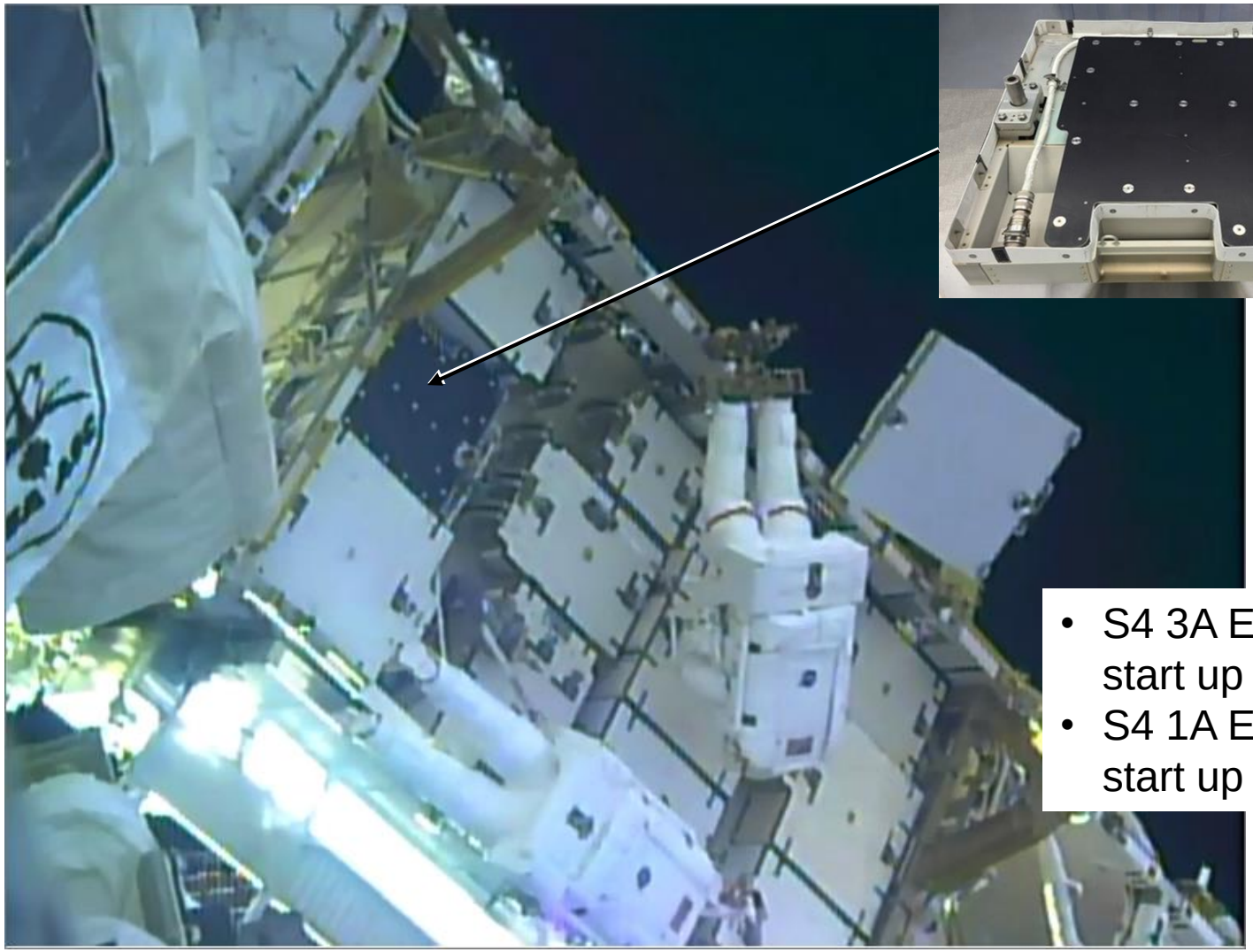
Robotic Installation of Li-Ion Battery ORU

- **S4 3A Batteries**
  - Robotically installed 12/31–1/2/2017
  - EVA and start up 1/6/2017
- **S4 1A Batteries**
  - Robotically installed 1/8–1/12/2017
  - EVA and start up 1/13/2017

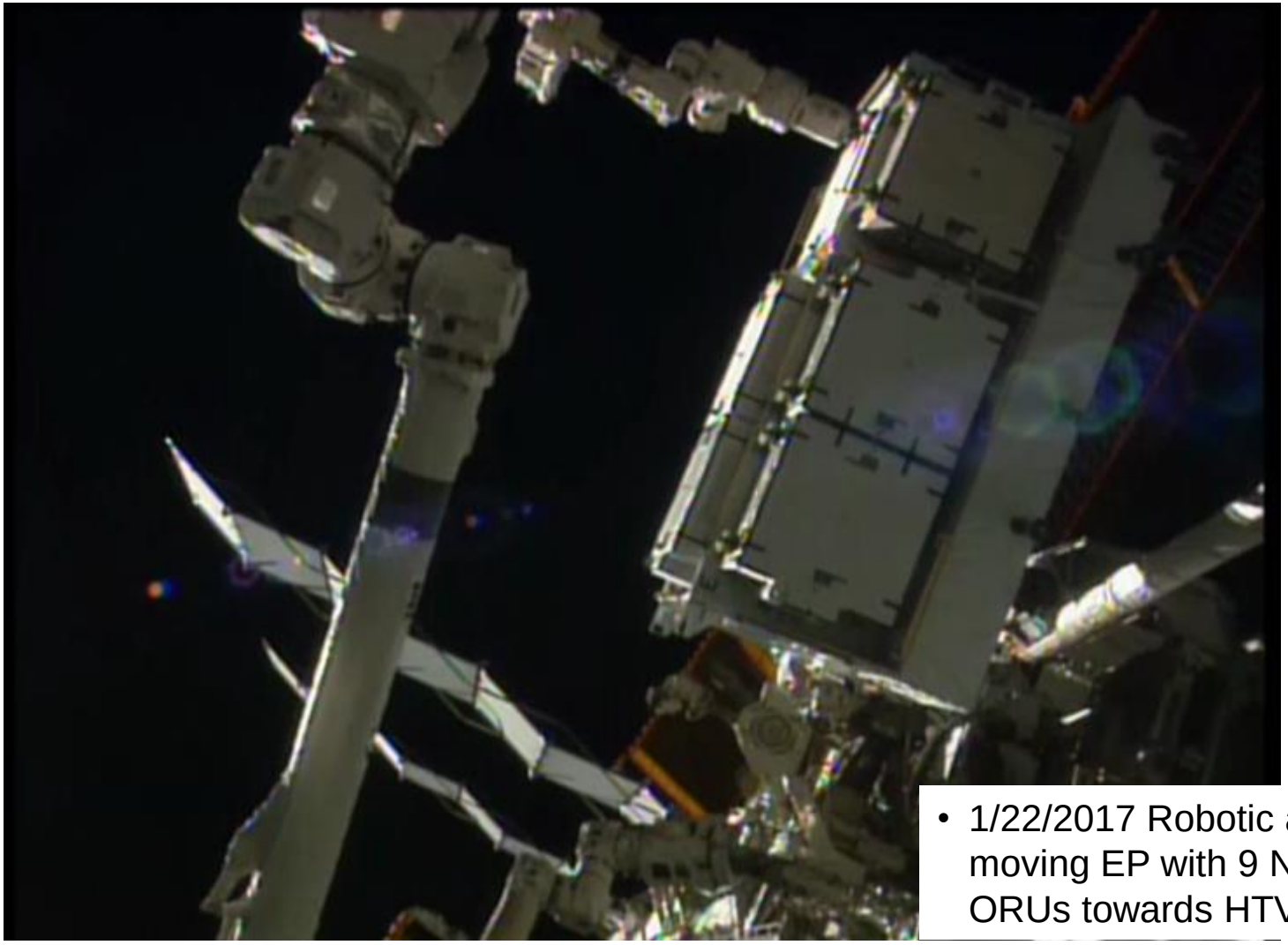


EVA Adapter Plate Installation



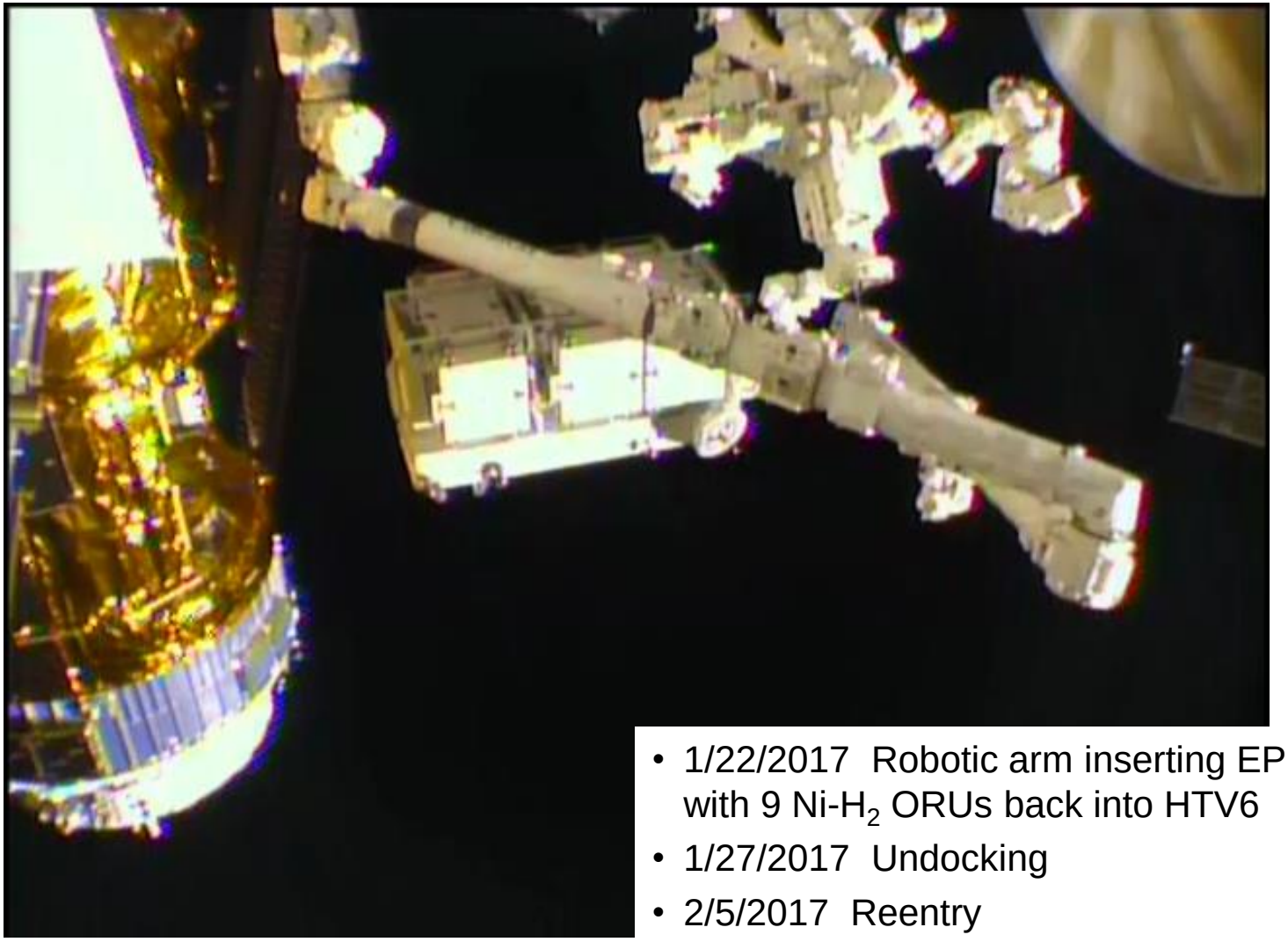
- S4 3A EVA and start up 1/6/2017
- S4 1A EVA and start up 1/13/2017

Robotic Disposal of Exposed Pallet with 9 Ni-H_2 ORUs



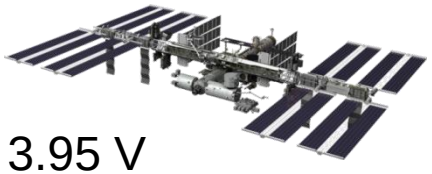
- 1/22/2017 Robotic arm moving EP with 9 Ni-H_2 ORUs towards HTV6

Robotic Disposal of Exposed Pallet with 9 Ni-H_2 ORUs

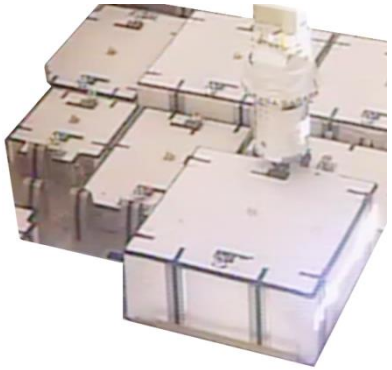


- 1/22/2017 Robotic arm inserting EP with 9 Ni-H_2 ORUs back into HTV6
- 1/27/2017 Undocking
- 2/5/2017 Reentry

Li-Ion Battery Status



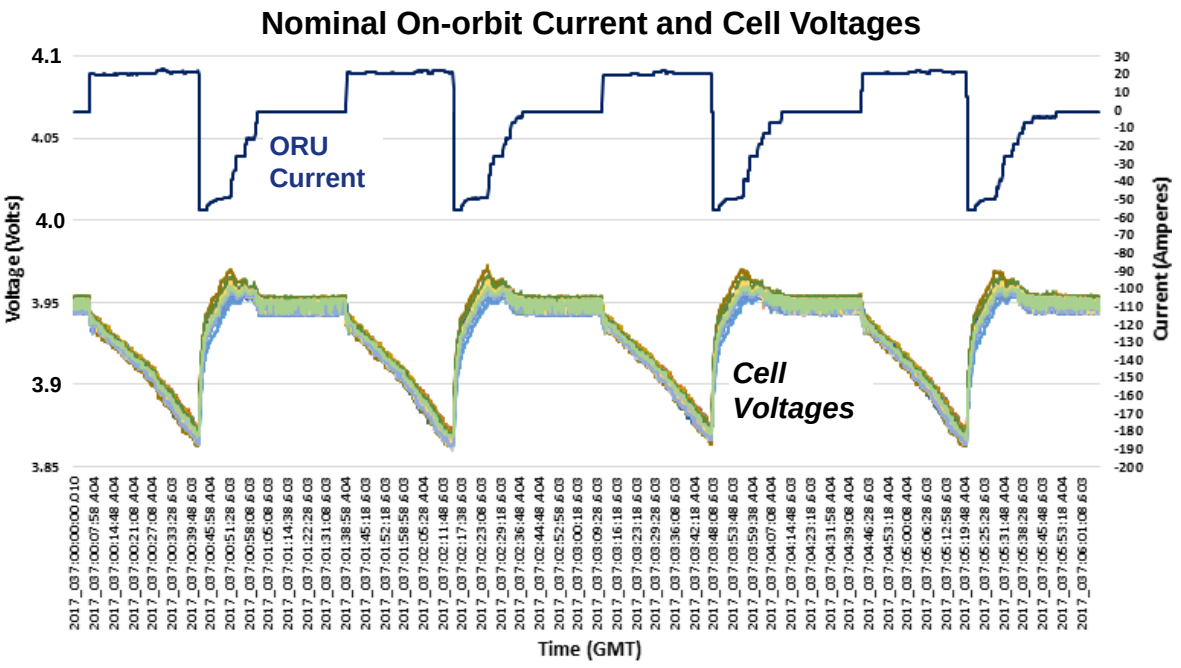
- Starting January 13, 2017, S4 Channels 3A and 1A are being operated using only Li-Ion Batteries
  - Batteries are performing well – capacity tests at EOCV of 3.95 V
    - 3A: 109.3, 110.3, 110.9 Ah (see page 18)
    - 1A: 114.0, 110.3, 112.3 Ah
  - Minor operational observations / forward work
    - Battery Charge Discharge Unit advisory message – upper Voltage Limit of 122 V exceeded (Limit to be updated to 124 V)
    - Occasional switchovers of redundant heaters (A to B, B to A) (Persistence time to be updated)
    - State of Charge calculation to be updated to increase accuracy
    - Adjustments to Charge Profile to be evaluated
- 17 of 27 Li-Ion batteries have been built and delivered
  - 6 on orbit, 11 in cold storage at KSC
- 16 of 25 Adapter Plates have been built and delivered
  - 6 on orbit, 10 in storage at KSC
- Future Launches
  - Next Lithium-Ion Battery launch on HTV7, NET Feb. 2018
  - Subsequent launches on HTV8- 2019, HTV9- 2020

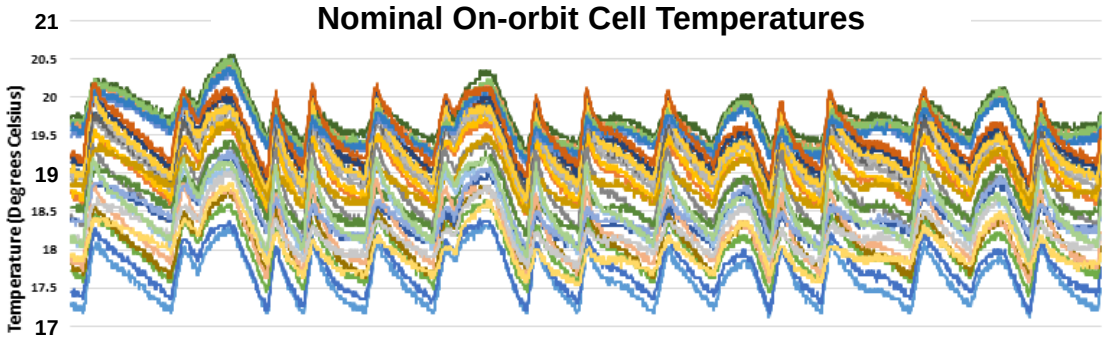


ISS Li-Ion Charge Control and Cycling

- Li-Ion charge current profile is based on cell voltages
- Cell bypass/balancing at EOCV every orbit
- EOCV ground command-able

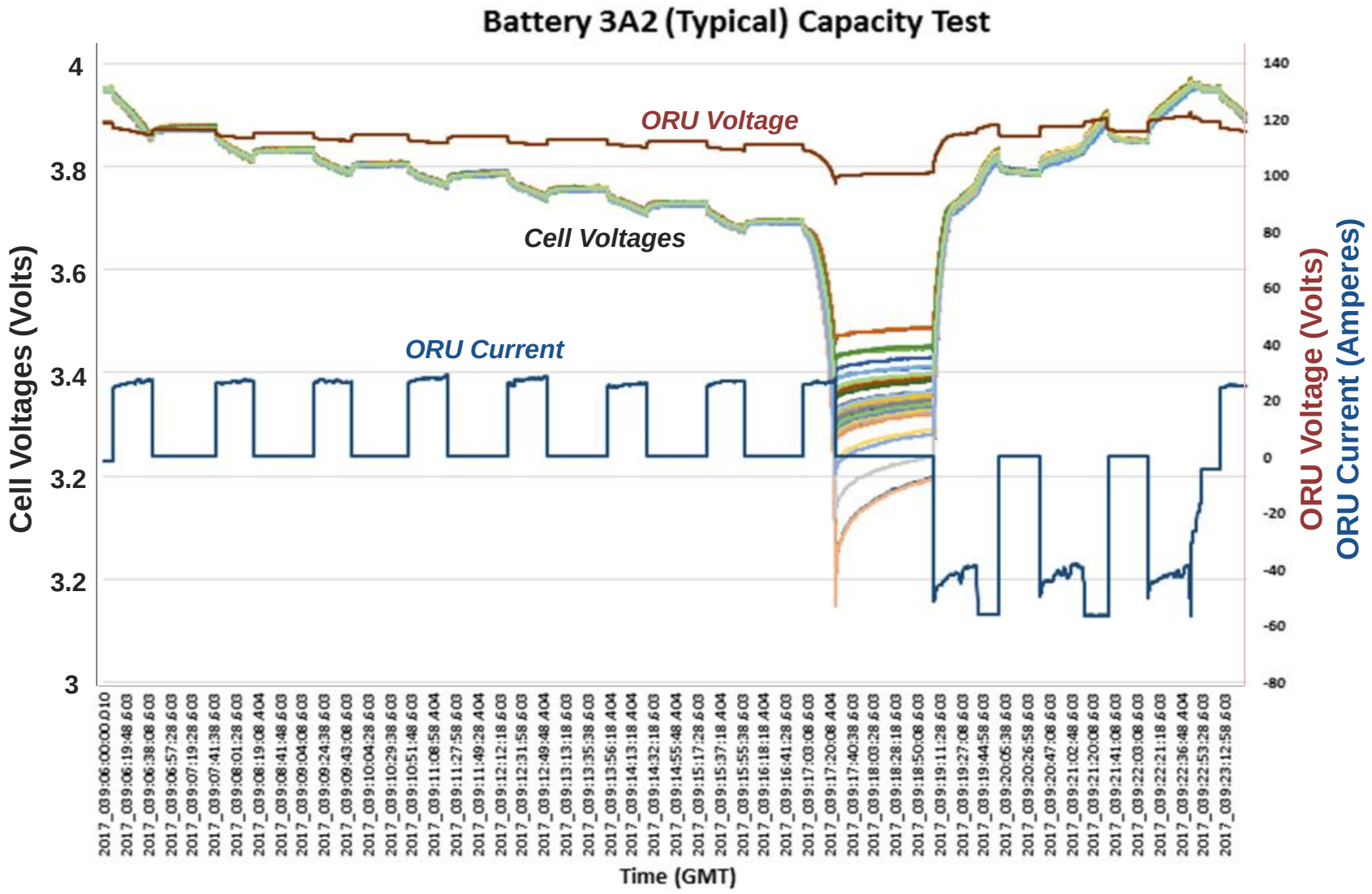
Charge Current Profile		
	Highest of the Cell Terminal Voltages	**Charge Current**
Point 1	EOCV + 19mV	55
Point 2	EOCV + 19mV	49
Point 3	EOCV + 18mV	44
Point 4	EOCV + 17mV	39
Point 5	EOCV + 16mV	36
Point 6	EOCV + 15mV	33
Point 7	EOCV + 14mV	30
Point 8	EOCV + 13mV	26
Point 9	EOCV + 12mV	22
Point 10	EOCV + 11mV	19
Point 11	EOCV + 10mV	16
Point 12	EOCV + 9mV	13
Point 13	EOCV + 8mV	10
Point 14	EOCV + 7mV	7
Point 15	EOCV + 6mV	4
Point 16	not applicable	1





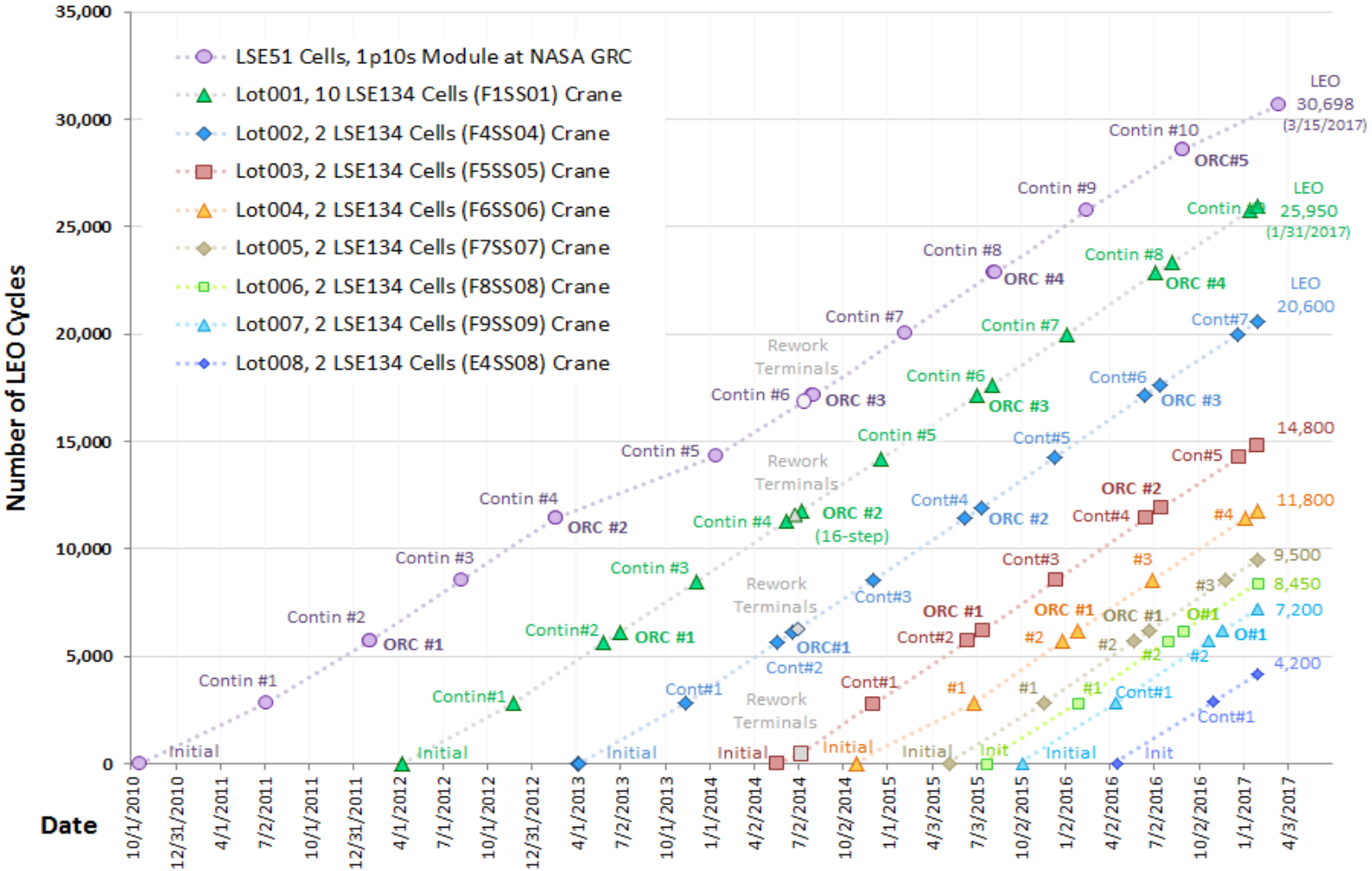
Data for Battery Channel 3A after ~30 days operation

ISS Li-Ion Charge Control and Cycling

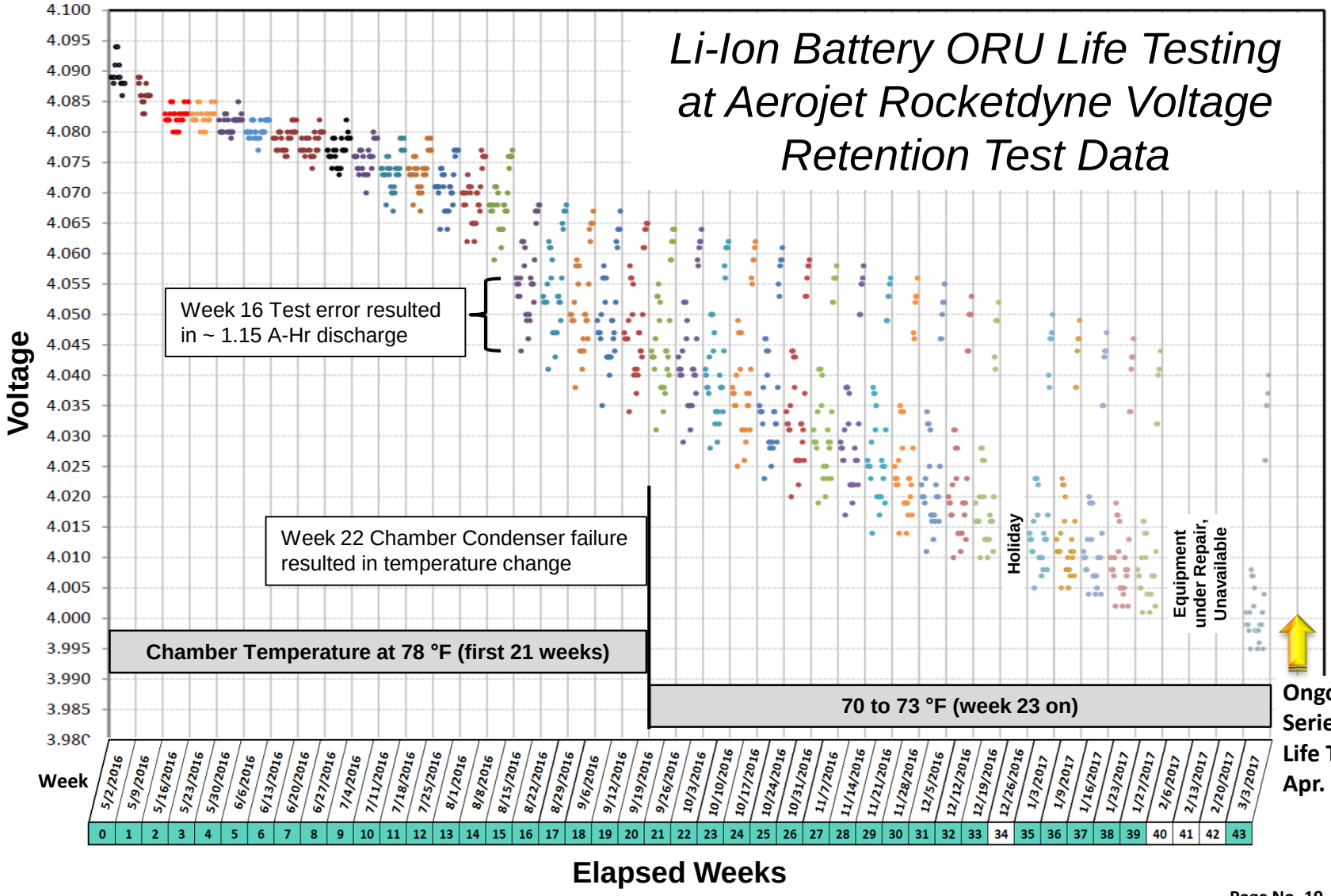


Life Test Program

- Cell Life Testing performed at Crane Lab and NASA-GRC

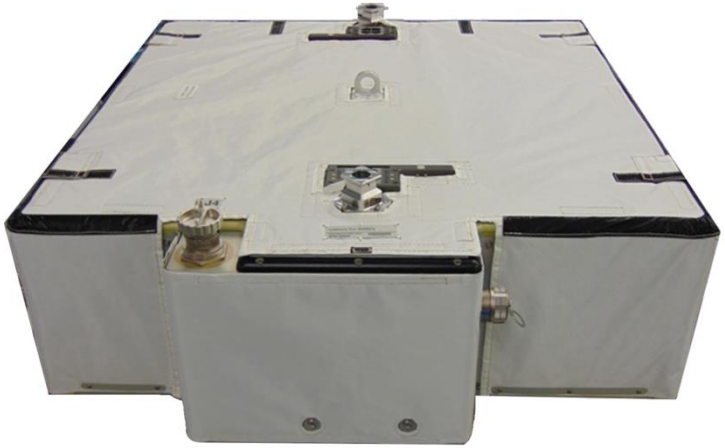


Life Test Program



ISS Li-Ion Battery Future Plans

- Data analysis for NESC (NASA Engineering & Safety Center) Thermal runaway propagation test performed October 2016 at the White Sands Test Facility
- Launch of remaining Li-Ion Batteries and Adapter Plates in 2018, 2019, 2020 to provide a full complement on ISS



➢ *First six batteries (2 power channels) operating successfully on orbit*

In Closing

- Questions?

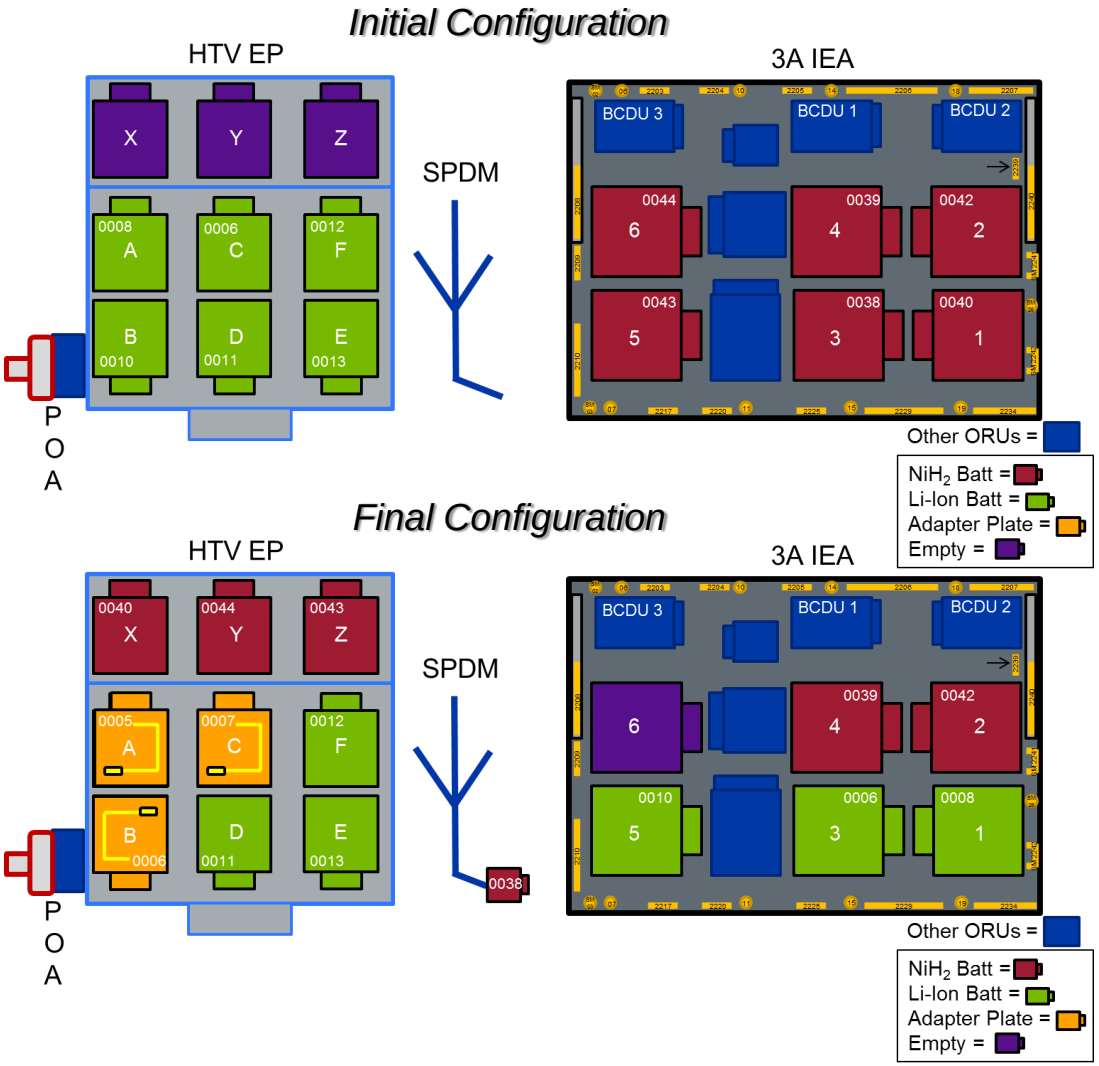
Backup Materials

- Installation Robotic and EVA sequence

Robotic Operations

3A Robotic:
(12/31/2016 – 1/3/2017)
1A Robotic:
(1/8/2017 – 1/12/2017)

Shift	Operation
1A	Ni-H_2: 5 > Z
1B	Ni-H_2: 6 > Y
2A	Li-Ion: B > 5
2B	Ni-H_2: 1 > X
3A	Li-Ion: A > 1
3B	Ni-H_2: 3 > EOTP
4A	Li-Ion: C > 3
4B	ROST: 1/5



EVA Operations

3A EVA: **(1/6/2017 & 1/13/2017)** **1A EVA:** **(1/13/2017)**
Adapter Plate A > 6
Ni-H_2 4 > AP 6
Adapter Plate B > 4
Ni-H_2 2 > AP 4
Adapter Plate C > 2
Release 1A IEA H1 Slot 2